# Emergency Electric Vehicle Power Bank

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ABSTRACT

The thesis gives an overview to the electric vehicle (EV) market and an analysis of their impact on the environment and points out not only the advantages of electric cars, but also the disadvantages that the consumer is faced with. In terms of the environment, real explanations and examples are given that point to the benefits of EVs, as well as the dangers that lie behind battery manufacturing. This shows also the outlook for the market of batteries. The costs of the implementation of this project were economically justified so that the system would be useful for the fuel companies, battery makers and consumers.

Then, the basic concept of an EV, the necessary components for its production and the control systems are explained. It also introduces the current situation on the EV market and shows existing technologies and modules to create a network that could help the owner of the EV car to get his or her car instantly charged.

The last part is about calculations, modelling and simulating of the electrical vehicle system. It examines the methods of turning an ordinary fully electric vehicle into a truly mobile EV. The theoretical part of the thesis includes capacity and power consumption calculations as well as a selection and design of the components. As a result, possible solutions were designed.

**Keywords** Battery, electric vehicle, charging, range extender.

**Pages** 30 pages

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# 1 INTRODUCTION

There could be a situation, a person who has miscalculated the charge on his or her fully electric vehicle (EV) and ended up in the middle of nowhere with only a regular gas station nearby. There is no suitable power grid in the district, which would provide fast charging for the EV. How can a customer charge an EV without wasting a lot of time?

The solution of this problem is the help of something like a huge power bank (PB), the size of a couple of car batteries. If fuel companies equipped each refuelling station with a couple dozen of such backup batteries, they would be able to rent them to EV customers that were in a difficult situation – by putting it into the trunk and plugging this PB to the circuit.

After that, the client could return the battery to another gas station, wherever it would be more convenient for him. This is the direct analogy of car or scooter sharing system. “Electrical vehicle range extenders” can be easily found all over the Internet and generally, these extenders look like huge and clumsy trailers.

This is an intermediate solution of upgrading regular gas stations, which would provide to the oil companies much more benefits than installing a full-service supercharging station. Firstly, the charging service at the station is free for the consumer while power banks can be leased for money. Secondly, this would be the best solution for those who are going for a long journey - to the mountains or the forest, for example, so the driver does not need to care about the state of charge of the car. It is just like having a canister with gasoline in the trunk. Thirdly, car manufactures can use unclaimed or used batteries to create these power banks.

For extreme conditions, such as extreme cold, manufacturers can provide thermostatic or at least well-insulated containers for the batteries, in case the EV driver runs out of the charge in frost, there will be at least something in the backup battery.

# 2 ELECTRICAL VEHICLE MARKET OVERVIEW

The two largest vehicle stocks in the world are based in Europe and the US. Based on them we can estimate:

- The population of the U.S. is about 328 million (Worldometer, 2019).
- 747 million people in Europe (Worldometer, 2019).

- The approximate ratio of cars in use in the U.S. is 276 million (U.S. Vehicles Registration Database, 2018).
- 308.3 million vehicles in circulation on the roads in the EU (ACEA Report, 2019).

- Actual number of refuelling stations in the U.S. is 122,552 (U.S. Convenience Store Count, 2017).
- The approximate number of petrol stations in Europe in 2017 is 115,000 (FuelsEurope, 2017).

Hypothetically conditions are given like an average internal combustion engine (ICE) car driver might need to refuel the car about once a week, so 276 million cars in 7 days equals 39 million cars refuelled on any given day. Hence, 317 cars per one station in a day only in the U.S. As well as, 382 cars per one station in a day in Europe.

The International Energy Agency forecasts up to 220 million electric vehicles by 2030, with the support of policy that emphasizes on more active fighting against climate change and cutting CO2 emissions than it was before (IEA, 2018).

As long as battery costs are falling, the International Energy Agency notes that government policy remains critical to making EVs attractive to drivers and manufacturers. According to the research, by 2025, the price of batteries will fall to 100USD/kWh. (IEA, 2019).

And based on the numbers above, we can notice that there will be lack of charging stations because, for now, actual number of supercharger stations is 1,636 all over the world (Tesla, 2019).

## 2.1 Manufacturers that dominate the market

Tesla Model 3 was the most popular EV in 2018. Tesla sold more than 138,000 Model 3, overtaking Chinese carmaker BAIC (92,000) and Nissan Leaf (85,000), JATO reports. In addition, in the beginning of 2019 Tesla started deliveries of the Model 3 in China and Europe, two biggest auto markets in the world, which provided boost in sales. (O'Kane, The Verge, 2019)

We need to remind ourselves that there is the Model S, which finished last year on the 5th place with 48,000 sold cars. In total Tesla sold 230,000 cars in 2018, while its closest competitor sold 152,000 cars. (O'Kane, The Verge, 2019)

Now we can admit justly that when it comes to battery technology, the Californian car producer is at least a couple of years ahead of its theoretical opponents. The President of Automotive Jerome Guillen (interview 29 November 2018) says:

“There are more batteries produced here for electric vehicles than in the rest of the planet combined. We would not be able to make all the vehicles we are making now if we didn’t have the Gigafactory.”

Moreover, according to recent news Tesla will start building a new Gigafactory in Shanghai and just launched building another one in Europe (EVANNEX, 2018).

## 2.2 Need for portable chargers

For now, there are 1,636 Supercharger Stations with 14,497 Superchargers all over the world (Tesla, 2019).

Tesla Superchargers take about 20 minutes to charge to 50%, 40 minutes to charge to 80%, and 75 minutes to 100% on the original 85 kWh Model S (Enel X, 2019).

A hasty business lifestyle makes people always worry about percentage of charge of their phones and watches, because if it will be discharged, then they could miss important call, notification, message or etc. The same situation with the electric cars - there is a saying that time is money, so busy person cannot wait for car to be charged.

There are many benefits with a power banks over a charging station. The biggest advantage is that it will save time for the EV owners and help them do not waste time and be always in time. In addition to this, such technology will also be at hand to EV manufacturers and fuel companies, for obvious reasons.

Advantages:

- Same as charging of the smartphone with the regular power bank. It is convenient and fast.
- The ability to set competitive price for the leasing of such batteries - financial flexibility.
- Backup batteries will pay off much faster than the built-in batteries.

Disadvantages:

- Like all batteries, they consume their resources and eventually must be replaced (InsideEVs, 2018).
- Such a battery will occupy a significant amount of the trunk.
- Batteries can be stolen or spoiled. Solution is making a lease agreement and using GPS-tracking system.

All the numbers above led us to the idea of this thesis:

- Provide to EV customers the service that will allow getting EV charged instantaneously.
- Let customers do not care about planning the road trip.
- Help EV costumers who found themselves in difficult or emergency situations. For example, person who is late for work/airport/etc. and he cannot wait 20 minutes to charge his car.
- Help to oil and gas companies smooth the transition from ICEs to EVs.
- Give the battery producers an opportunity to realize unclaimed goods, such as completely serviceable battery modules from damaged/defective cars.

# 3 CLIMATE CHANGE

During the past few decades, the scientific community has concluded that we are responsible for many of the disasters that are happening and which will happen in the future. Since the schoolyard, we know that CO2 emissions significantly increase the average temperature on the Earth.

## 3.1 Effects on amount of CO2 in the atmosphere

Carbon dioxide enters the Earth's atmosphere from natural and artificial sources. The first covers volcanic eruptions, respiration of aerobic organisms, that is, those that need oxygen to generate energy, as well as fermentation or decay of organic remains. Second, includes the burning of coal, gas or oil products. Starting from the 19th century, need for new energy sources began to grow dramatically, and as a result - the natural cycle of carbon dioxide was disrupted and its concentration in the atmosphere began to increase. (CHE, 2017)

Prior to the beginning of industrialization age, the concentration in the atmosphere of CO2 over the past 800,000 years did not exceed 280 ppm, as we can see from Figure 1. On May 11, 2019, for the first time in the Earth's history, it has turned out to be above the 415 ppm (ScienceAlert, 2019). In confirmation of this, the Figure 1 shows the reconstructions of atmospheric $CO_2$ back 800,000 years:

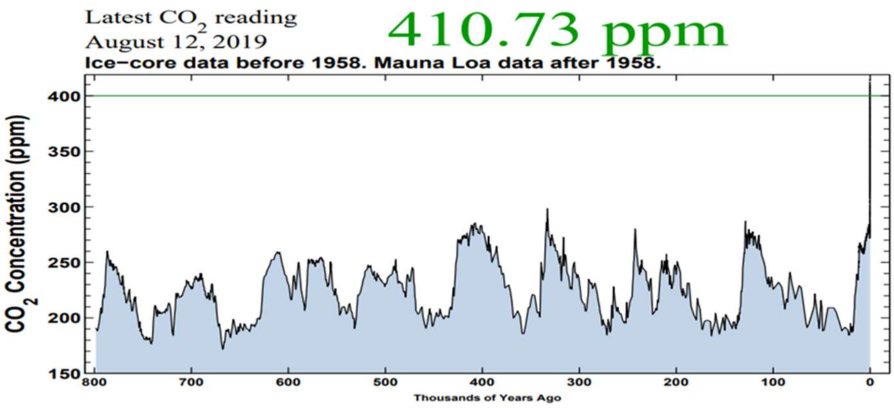


*Figure 1. The Keeling Curve (Scripps Institution of Oceanography, 2019)*

Scripps geochemist Ralph Keeling (interview 19 September 2018) says:

«The rise in $CO_2$ is unambiguously caused by human activity, principally fossil-fuel burning. This is clear from the numbers: We know how much fossil fuel is converted into $CO_2$ each year and emitted into the atmosphere. (…) At no point in this period were levels as high or increasing as fast. No surprise because it is only recently that we humans have been burning billions of tons of fossil carbon each year.»

The weather is not constant, it is always changing, but short-term, the climate is constant. In ideal and long-term conditions, it changes, but it is barely detectable. Then the climate change implies that the changes are fostered by pressure from external forces. So, is there a direct correlation between the amount of $CO_2$ in Earth's atmosphere and the planet's temperature rise? Yes, there is. When solar radiation reaches Earth's atmosphere, part of it reflects back into space and other part passes through the earth and absorbs by the Earth. That is prompting the Earth's surface to heat up. Heat from the Earth is radiates outward and absorbs by the "greenhouse gases". (National Park Service, 2019).

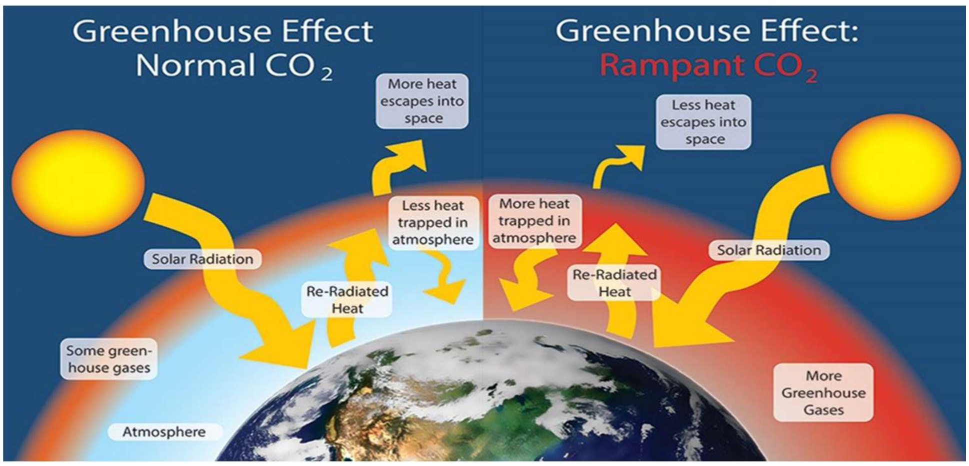


*Figure 2. Greenhouse Effect (National Park Service, 2019)*

In Figure 2 on the left side of the picture, there are naturally occurring greenhouse gases illustrated – carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) — normally trap some of the sun's heat, keeping the planet from freezing. Astronomical and geophysical forces, as well as the planet's internal dynamics, were the main factors of climate change during the last 4.5 billion years. (National Park Service, 2019).

The right side in Figure 2 is human activities, such as the burning of fossil fuels that increase greenhouse gas levels, leading to an enhanced greenhouse effect. The result is global warming and unprecedented rates of climate change. (National Park Service, 2019).

### 3.2 Warning to humanity

From the Anthropocene equation (Owen Gaffney and Will Steffen research, 2017) we can see that the climate changes caused by people are significantly superior to those caused by natural events over the last 7000 years:

"Over the last 7000 years the rate of change of temperature was approximately −0.01°C/century. Over the last hundred years, the rate of change is about 0.7°C/century (Intergovernmental Panel on Climate Change (IPCC), 2013), 70 times the baseline – and in the opposite direction. Over the past 45 years (i.e. since 1970, when human influence on the climate has been most evident), the rate of the temperature rise is about 1.7°C/century (NOAA, 2016), 170 times the Holocene baseline rate." (The Anthropocene Review, 2017, 3)

In 1992 the Union of Concerned Scientists and more than 1,700 scientists, including the most living Nobel laureates in science, signed the World Scientists' Warning to Humanity. The manifesto states that urgent changes are necessary to avoid the consequences of the current course: scientists expressed concern about the existing or potential damage to the planet associated with the depletion of the ozone layer, fresh water, oceans, forests loss, destruction of biodiversity, climate change and continued population growth. (Union of Concerned Scientists, 1992).

On the 25th anniversary of the first warning, in 2017, the Second "Warning to Humanity" appeared in BioScience magazine, signed by 15,364 scientists from 184 countries. Scientists noted some successes in the new manifesto, in particular, a decrease of the ozone-depleting substance's amount around the world. This shows that humanity can change the world for the better if we will continue to act decisively. (BioScience, Volume 67, Issue 12, 2017, p. 1026–1028).

### 3.3 Consequences of the climate change and how to handle it

Climate change is changing our economies, health, and communities in many ways. Scientists warn that if we cannot significantly stop climate change at this stage, the results could be disastrous (Master Kisi-Kisi SBMPTN Saintek, 2019, P. 455). Here is what can happen if the Earth warms even more (Warm Heart Worldwide, n.d.):

- When the water is heated, its volume increases and the oceans absorb more heat than the earth, thus sea level rises.
- Sea level will also rise due to melting glaciers.
- Coasts may be flooded.
- Areas with heavy rainfall can become hotter and drier.
- Many lakes and rivers can dry.
- The spread of drylands will create difficult conditions for growing crops.
- The amount of drinking water can decrease significantly, which will affect food production and agriculture.
- Many species of plants and animals can disappear from the Earth's face.
- Hurricanes, tornadoes, and other storms caused by climate change and water vapour may become more common.

To say that if we will turn away ICE cars, then we will save Earth from air pollution or climate changes - it is not true. The true is that this problem requires comprehensive solution. Of course, electric cars are unequivocally clean, because they do not burn fuel. They do not have ICE, gas tank and exhaust pipe, they are considered to be zero-emissions cars. But EV cars affect the environment also in other ways. EVs are not dynamo-machines and they are not powered by hydrogen – it works on electricity; which, in turn, is generated from a number of different sources: from nuclear plants to natural gas and coal plants. Battery production is also has a big impact on environment pollution. The production itself suggests dust, fumes, wastewater and other environmental impacts such as water shortages and toxic spills from mining, a heavily polluted river, or air pollution, which can alter ecosystems and contaminate the environment for decades to come. (World Economic Forum, 2017).

We are fully aware that move away from fossil fuels at once it is not possible. If we refuse oil, coal and gas right now, then we will have nothing to refuel our cars; there will be a shortage of electricity and plastics (INSH, 2018). Therefore, the most reasonable way to solve this problem is to phase out fossil fuels. With a systematic transition from polluting industries to alternative energy sources, from ICE cars to electric vehicles. This is the long game; we just need to start playing it and one day we will not even notice how find ourselves in a beautiful world of the future.

# 4 ELECTRIC VEHICLE BASICS

In order to make any electric car move, four key components are required, without which we cannot do it (Golden Motor, n.d.):

**Electromotor** – Tesla Model S/X uses 3-phase, 4-pole Induction Motor; Tesla Model 3 uses 3-phase, 6-pole, internal permanent magnet switched reluctance motor. (CleanTechnica, 2019). A number of reasons makes Induction motor a great option for EVs (Choubey, 2017).

Here is a list of some good features:

- A 3 phase Induction motors are reliable and endurable.
- They are highly efficient and have low weight/kW power requirement.
- With the help of VVVFD drives, these motors have efficient start with low current and high starting torque.

**Invertor (or controller)** – This is an electronic device that inverts direct current from the battery into a 3-phase alternating current for powering the motor wheel. In addition, it regulates the frequency supplied to the motor, depending on the position of the gas pedal (Golden Motor, n.d.). There are two types of systems that help an electromotor became more efficient: VFD – Variable Frequency Drive and VVVFD stands for Variable Voltage Variable Frequency Drive. Main purpose of both is to control the speed of a motor and current by varying the voltage and frequency. (Craig Hartman, 2014; Bibhuprasad Ganthia, 2015, p. 3).

The propose of VFD and VVVFD is to keep a certain V/Hz ratio to the motor while its running. And as far as we know – Frequency (Hertz) is directly related to speed of the rotor (RPM). In other words, the bigger frequency, the faster the rotor rotates. If the system does not require the motor to run at full speed, the VVVFD will reduce the frequency and voltage in accordance with the technological requirements of the motor. For example, a 230 VAC, 60 Hz electromotor needs a V/Hz ratio of 3.83 (230/60 = 3.83). When a V/Hz drive changes its frequency, it also changes the output voltage to keep the ratio constant. So, if electromotor able to run at 30 Hz (half speed), the controller will cut 230 VAC twice, se the electromotor will need only 115 VAC as output from the drive. (Deep Bhatt, 2017).

**Battery** – rechargeable battery assembled of cells and connected to the BMS (circuit board for protecting cells from scanty or overcharge). Will be described below what kind of battery have been chosen for the thesis and why. (Golden Motor, n.d.).

**Controls** – a system that usually includes gas pedal, brakes, cruise control and reverse. The gas pedal and brakes are mandatory, the rest are auxiliary. (Golden Motor, n.d.).

# 5 TESLA

The choice is justified by performance indicators, as well as the "canonicity" of the brand, which makes it the trendsetters in the industry.

Battery degradation is one of the main concerns when buying an electric car such as the Tesla Model S/X/3. From the experience of using smartphones and other gadgets, we know that lithium-ion batteries tend to degrade quickly after a certain number of charge-discharge cycles, even if you treat them very carefully.

A group of Tesla-owners at the Dutch-Belgian forum has compiled extensive statistics on more than 350 Tesla cars from around the world (Electrek, 2018).

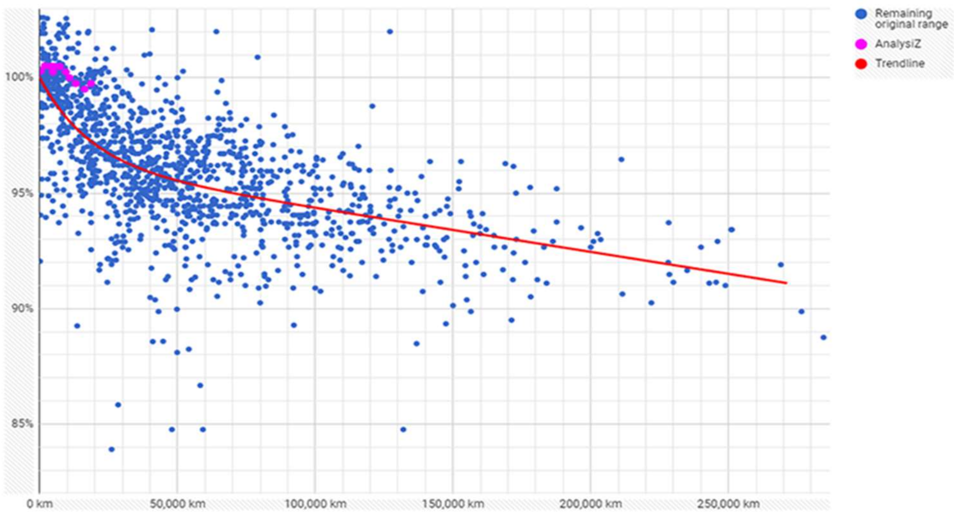


*Figure 3. Tesla Model S/X Mileage vs Remaining Battery Capacity (Electrek, 2018)*

For now, the most complete statistics have been collected for the first 50,000 kilometres. As from the graph above, in this segment the Tesla Model S/X batteries degrade especially intensively. Here they lose up to 5% of their capacity, this happens literally in the first months or years of operation of the car, depending on the intensity of use. (Electrek, 2018).

This numbers will make everyone suspicious. If this trend continues, then after 250,000 km, customer will have only 77.4% of the original capacity of the battery. Moreover, this is without considering that degradation can accelerate over time.

Nevertheless, according to the collected data, in order to lose another 5% of the battery capacity, customers will have to wait a lot more time. According to statistics, in most cases, the battery capacity still exceeds 90% after 250,000 km. The trend line shows a drop to 90% of the initial capacity will occur somewhere in the range of 300,000 km. (Electrek, 2018).

Unfortunately, this statistics not yet complete and not representative. Firstly, only forum users enter data about their cars - and these are by default more advanced customers, who know better in which modes it is better to operate the car. Secondly, the indicator of the stored battery capacity for an interested owner may become something like a reason for pride - as a result, those car owners who have achieved a higher indicator will mainly enter information.

By the way, for the Model 3 model, Tesla has established a guarantee that the battery capacity will not fall below 70%. For a standard battery, the warranty is eight years or 160,000 km. For comparison, the Chevy Bolt EV guarantees a minimum of 60% capacity, and the Nissan Leaf - 66% capacity for the same period and mileage. That is, the guarantee terms at Tesla are slightly better than the competitor’s.

## 5.1 **Nissan Leaf**

Extensive objective research of data from 1382 Nissan Leaf electric cars, sold in 2011-2017, shows more severe battery degradation than on Tesla’s cars. Original 24 kWh batteries degrade by 20% after five years of use, and a newer 30 kWh battery loses capacity level even faster. Figure 4 shows that the loss of 20% takes place on average faster than in three years. (Electrek, 2018).

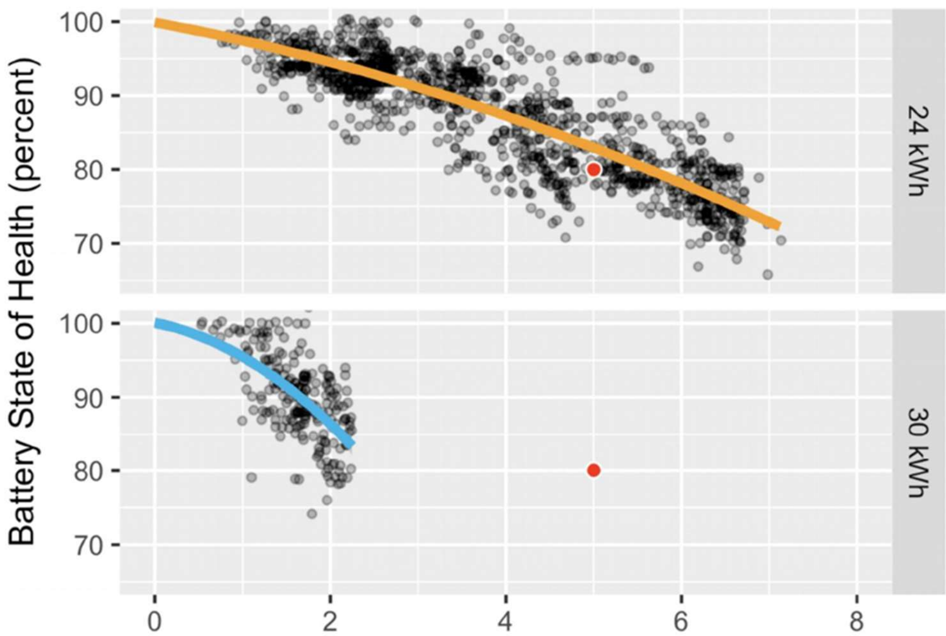


*Figure 4. Nissan Leaf Battery State of Health vs Years Of Use (Electrek, 2018)*

## 5.2 **Type of the battery**

There are some more reasons to choose Tesla's products. For example the Tesla Model S/X battery pack comprises of numerous modules in case of it is taken apart. This can be clearly seen in the Figure 5 below:

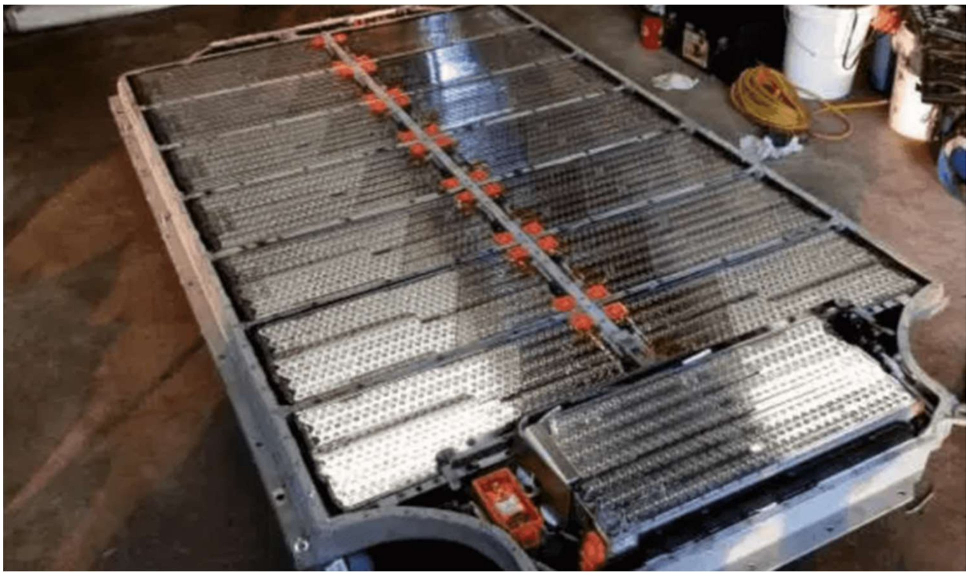

*Figure 5. Tesla Model S Battery Pack (Hackaday, 2014)*

It consist of 16 battery modules, also known as "bricks". Each of them includes 444 Panasonic 18650NCR cells 3400 mAh nominal capacity (Electrek, 2016). The 85-type, has the following specifications:

| | |
|---|---|
| Capacity (ideal) | 5.3 kWh (233 Ah) |
| Discharge Current (10s) | 1,000 A (~4.3C) |
| Discharge Current (continuous) | 233 A (~1C) |
| Discharge Power (continuous) | 5 kW |
| Charge Power (max, 10m) | 8 kW |
| Charge Power (continuous) | 5 kW |
| Cell Configuration cells | 6 series of 74 parallel (6s74p) 444 |
| Weight | 26.3 kg |
| Dimensions (approximate) | 685 x 300 x 75 mm |
| Voltage (nominal) | 22.2 V |
| Voltage (max) | 25.2 V |
| Voltage (minimum) | 18 V |

*Table 1. Tesla Battery 85-type specifications (HSR Motors, n.d.)*

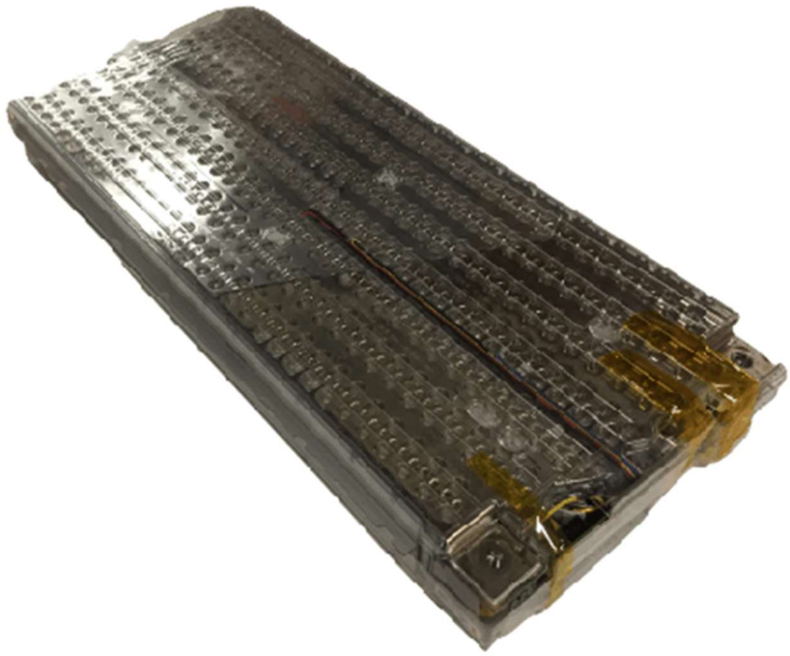

*Figure 6. 85-Type battery module (EV Europe, n.d.)*

This battery model have been chosen because of mobility. As mentioned above, the purpose of my thesis is to give the consumer the opportunity to “refuel” their EVs in a very short period without using of super-charging stations, and help to make the electric car truly mobile. In addition, expand the market for used battery modules that, for whatever reason, have been recycled, but can continue to serve and bring benefits.

Since this type of battery module has a small size: 685 x 304 x 77mm and a weight of 26.3 kg. For comparison, the weight of the most common batteries in modern cars is from 15 to 18 kg. This allows making this in the way of self-service - a person who wants to use this service will be able to take a couple of modules and place it into the trunk and connect them to the car network independently.

The modularity is one of the main features of this system. The consumer himself chooses how much additional energy he needs. Judging from the graphs given above, from 2 to 4 additional modules connected in parallel will be sufficient for the EV owners; which will give an additional 10.6 to 21.2 kWh of energy.

# 6 CALCULATIONS

## 6.2 Needed power

### 6.2.1 Mathematical model of the motor

Tesla uses a 3-phase 4-pole and 3-phase 6-pole AC motors. These require complex electronics and mathematics to be controlled but are highly efficient. Here, to show a simplified vehicle model was used a brushed DC motor that fitted to a Tesla motor as much as possible. Following figure shows the equivalent circuit of a brushed DC motor:

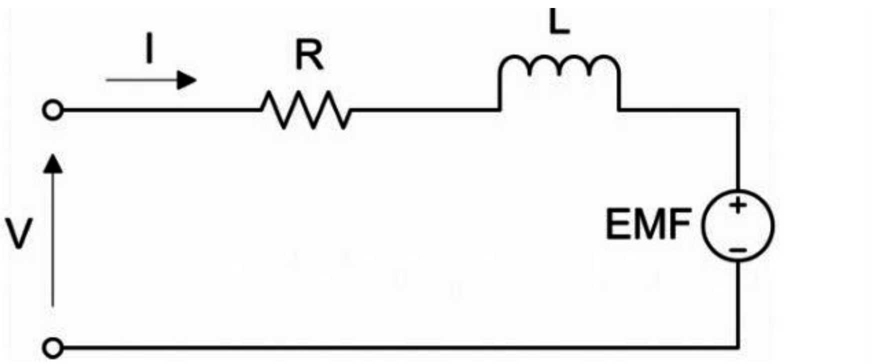


*Figure 7. DC Motor Equivalent Circuit (Eliott Wertheimer, 2018)*

The voltage across the resistor is:

$$V = IR \tag{1}$$

The voltage across the inductor is:

$$V = L\frac{dI(t)}{dt} \tag{2}$$

According to second Kirchhoff's law, the voltage law says that for a series closed-circuit path, the algebraic sum of all the voltages around any closed loop in the circuit is zero:

$$V = I(t)R + L\frac{dI(t)}{dt} + E(t) \tag{3}$$

The torque in a DC motor can be written as follows:

$$T(t) = K_T I(t) \tag{4}$$

Where $K_T$ is the torque motor constant that is defined by the manufacturer.

In addition, the back EMF (electromotive force) defined by:

$$E(t) = K_E \omega(t) \tag{5}$$

Where $K_E$ stands for the back EMF constant and ω is rotational speed of the motor.

Thus, we get (Eliott Wertheimer, 2018):

$$V = I(t)R + \frac{LdI(t)}{dt} + K_E\omega(t) \quad (6)$$

Then transform torque equation for a DC motor and equation above to Laplace domain (Eliott Wertheimer, 2018):

$$V(s) = RI(s) + sLI(s) + K_E + \omega(s) \quad (7)$$

$$T(s) = K_T I(s) \quad (8)$$

According to two equations above, one describes the relationship between voltage, current and rotational speed of the DC motor, and second one describes relationship between torque and current. Therefore, to get equation that links voltage to torque, and afterwards, get transfer function where voltage is an input and torque is an output (Eliott Wertheimer, 2018):

$$I(s) = \frac{V(s) - K_E\omega(s)}{sL+} \quad (9)$$

Hence, equation for torque is (Eliott Wertheimer, 2018):

$$T(s) = K_T \frac{V(s) - K_E\omega(s)}{sL+R} \quad (10)$$

Since Tesla does not publish technical specifications of its products, then next technical information was found on the owner's forum (Tesla Motors Club, 2015):

$R$ = 5.3 $*$ 10$^{-3}$ $Ohm$
$L$ = 493 $*$ 10$^{-9}$ $Henrys$
$K_E$ = 0.12 $Vs/rad$
$K_T$ = 0.25 $Nm/Amp$

From here, equation that describes DC motor can be written as:

$$T(s) = 0.25 \frac{V(s) - 0.12\omega(s)}{493 * 10^{-9}s + 5.3*10^{-3}} \quad (11)$$

In result, torque output as a function of rotational velocity and the voltage applied to the motor. (Eliott Wertheimer, 2018).

### 6.2.2 Forces that affect on the car

School physics will help to understand how much power and battery capacity. In order to understand how a car works, and identify what forces act on it, then it will look like Figure 8:

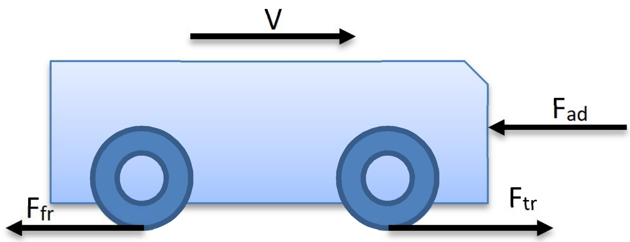


*Figure 8. Forces that affect on the car*

There are three forces that act on the car:

$F_{tr}$ – the tractive force;
$F_{fr}$ – the rolling friction resistance;
$F_{ad}$ – the aerodynamic drag;

The traction force pulls the car and the drag forces that slow it down. So the car can run under this condition (Electrotransport, 2017):

$$F_{tr} \geq F_{fr} + F_{ad} \quad (12)$$

These forces are equal to (Electrotransport, 2017):

$$F_{fr} = \mu m g \quad (13)$$

μ – Coefficient of rolling friction (rubber / asphalt) (average μ = 0.02)
m – Mass of the car (kg)
g – Acceleration of gravity (9.81 $m/s^2$)

$$F_{ad} = \frac{C_d S \rho V^2}{2} \quad (14)$$

$C_d$ – Coefficient of air resistance / Drag coefficient
S – Frontal area of the car ($m^2$)
ρ – Air density (1.29 $kg/m^3$ under normal conditions)
v – Car speed, m/s
And overall efficiency of the system is 70%.

Torque generated by the motor converts into the tractive force with the help of wheels and friction force (Eliott Wertheimer, 2018):

L – the wheel radius (from standard 245/45 R19 wheel, radius is 0.35m)
$G_r$ – the gear ratio (single speed gearbox with a ratio of 9.73:1 for Tesla Model S/X and 9.1:1 for Tesla Model 3)

For Model S and X:

$$F_{tr} = \frac{T}{L} G_r = 27.8T \tag{15}$$

For Model 3:

$$F_{tr} = \frac{T}{L} G_r = 26T \tag{16}$$

According to the 2nd Newton's Law, the case when several forces act on a material point, each of them informs the point of the acceleration determined by Newton's second law as if there were no other forces (the principle of independence of the forces). Therefore, the resulting acceleration of the material point can be determined according to Newton's second law, substituting the resultant force into it.

$$\sum F = ma \tag{17}$$

In our case:

$$0.7 * 27.8T - F_{fr} - F_{ad} = ma \tag{18}$$

Alternatively, equivalent to the vehicle dynamics of the system below (Eliott Wertheimer, 2018):

$$\frac{0.7*27.8T - F_{fr} - F_{ad}}{m} = \frac{dv}{dt} \tag{19}$$

### 6.2.3 Power calculations

To make the power calculations fast with visible results adjustable electrical vehicle model had been compiled by using MATLAB/Simulink.

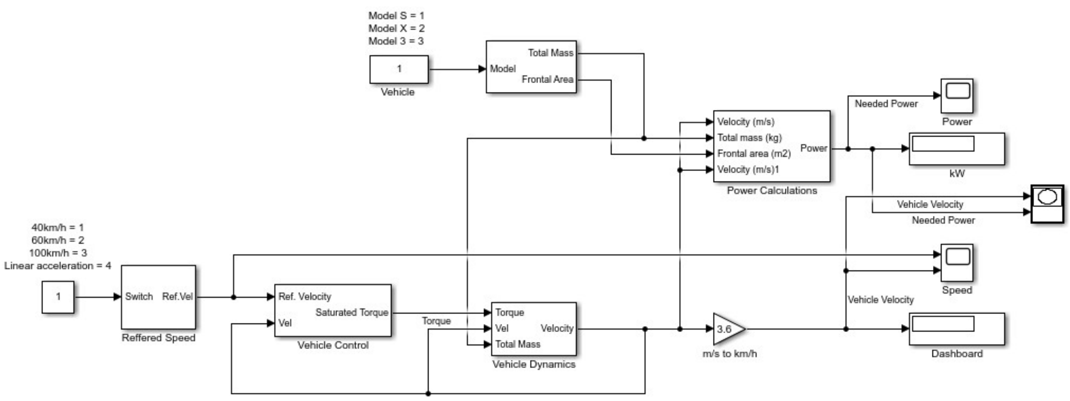


*Figure 9. MATLAB/Simulink electrical vehicle model*

User can change vehicle model and referred speed by changing numbers in blocks "Vehicle" and "Referred speed" respectively.

There is a simple formula for calculating power:

$$P = FV \tag{20}$$

The required power depends on the speed of the car (Electrotransport, 2017). Substitute formula here and get:

$$P_{engine} = \left(\mu m g + \frac{C_d S \rho V^2}{2}\right) V \tag{21}$$

Following specifications show some technical specifications for chosen model (Tesla, n.d):

| | | |
|---|---|---|
| $C_d$ = 0.23 (Model 3), | 0.24 (Model S, X) | |
| S = 2.22m$^2$ (Model 3), | 2.34m$^2$ (Model S), | 2.59m$^2$ (Model X) |
| m = 1864kg (Model 3), | 2170kg (Model S), | 2300kg (Model X) |
| μ = 0.02 | | |
| g = 9.81 m/s$^2$ | | |
| ρ = 1.29 kg/m$^3$ | | |

*Table 2. Vehicle specifications*

Now the battery can be picked up by calculating the power. For example, take one of the most popular EV cars (Digital Trends, 2020) – Tesla and calculate what power is required to accelerate to 40, 60 and 100 km/h and keep specified speed.

Calculations for Model S:

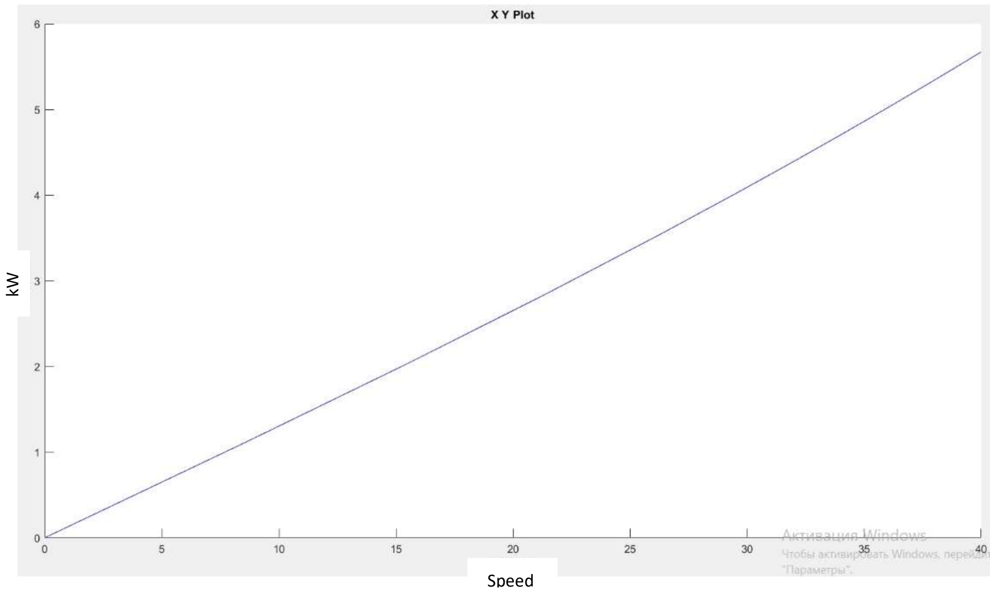


*Figure 10. Correlation of speed and engine power consumption for Tesla Model S at 40km/h (5.669 kW)*

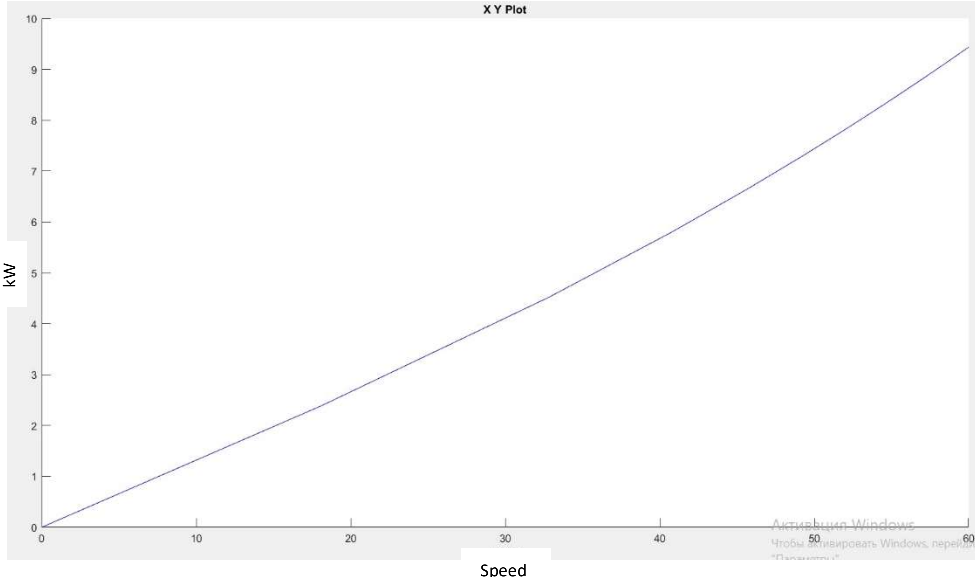


*Figure 11. Correlation of speed and engine power consumption for Tesla Model S at 60km/h (9.435 kW)*

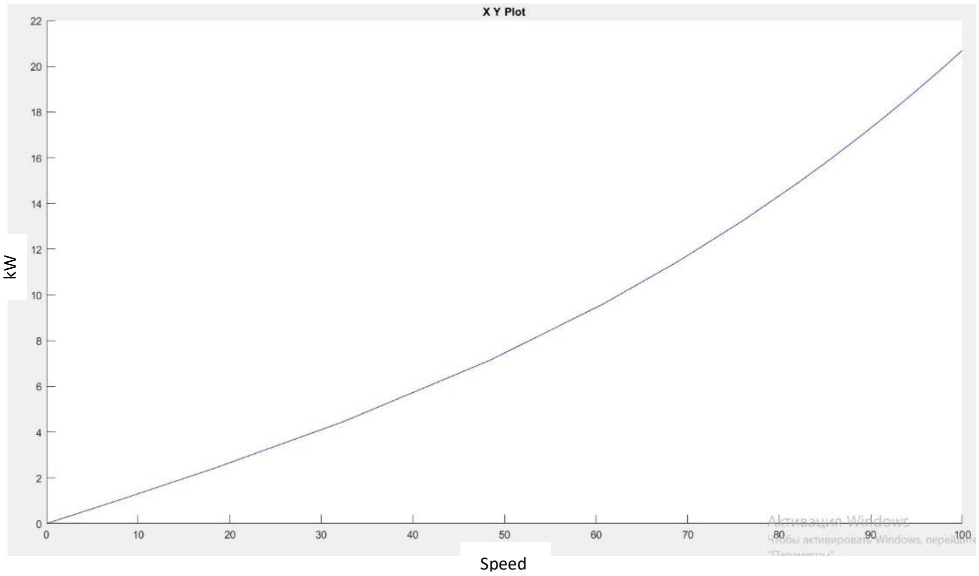


*Figure 12. Correlation of speed and engine power consumption for Tesla Model S at 100km/h (20.69 kW)*

Calculations for Model X:

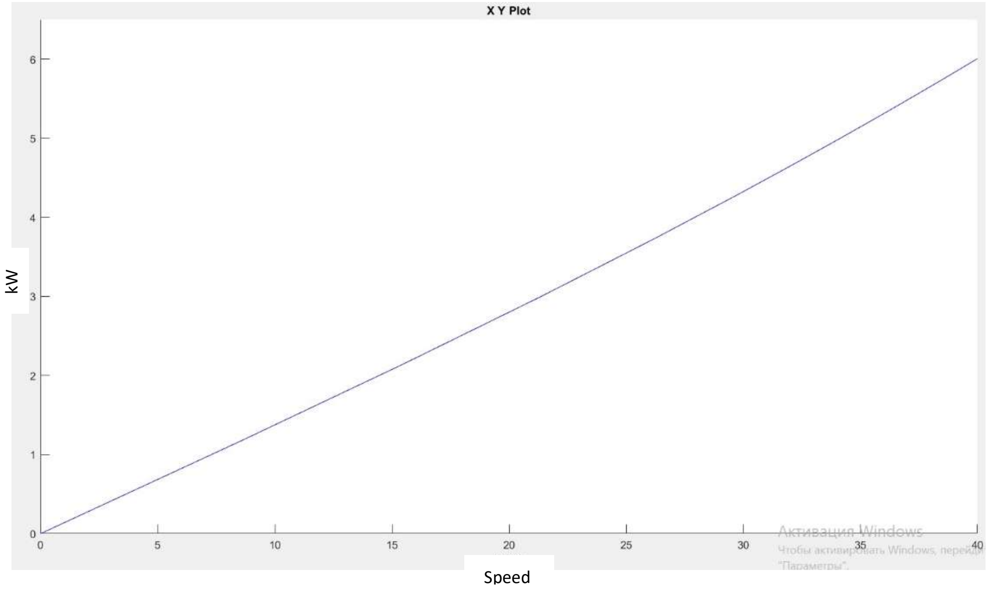


*Figure 13. Correlation of speed and engine power consumption for Tesla Model X at 40km/h (6.006 kW)*

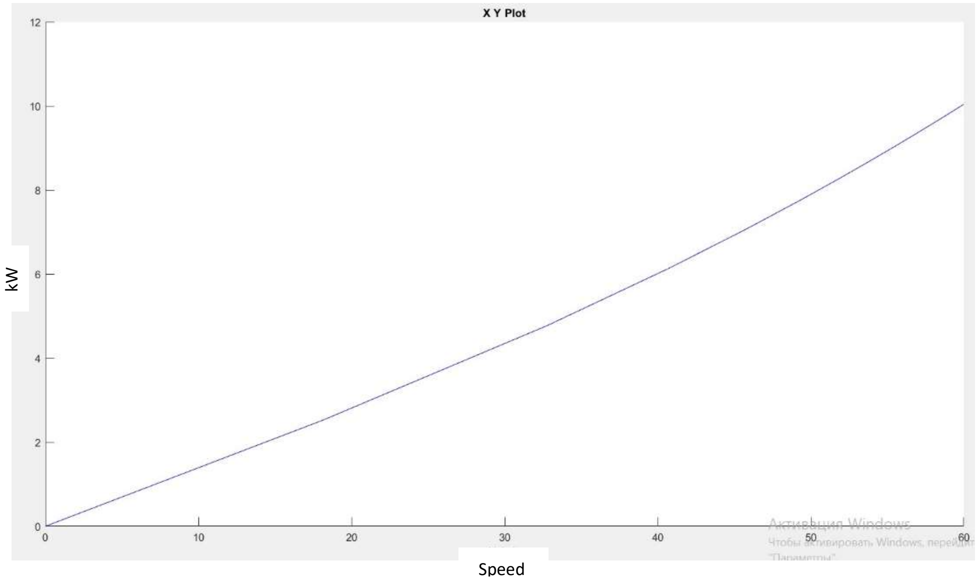


*Figure 14. Correlation of speed and engine power consumption for Tesla Model X at 60km/h (10.04 kW)*

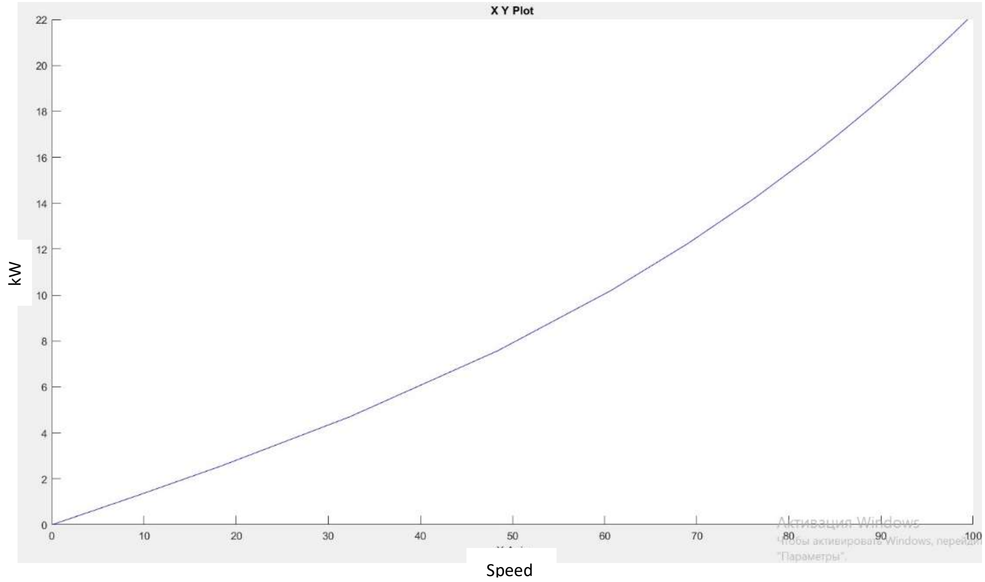


*Figure 15. Correlation of speed and engine power consumption for Tesla Model X at 100km/h (22.23 kW)*

Calculations for Model 3:

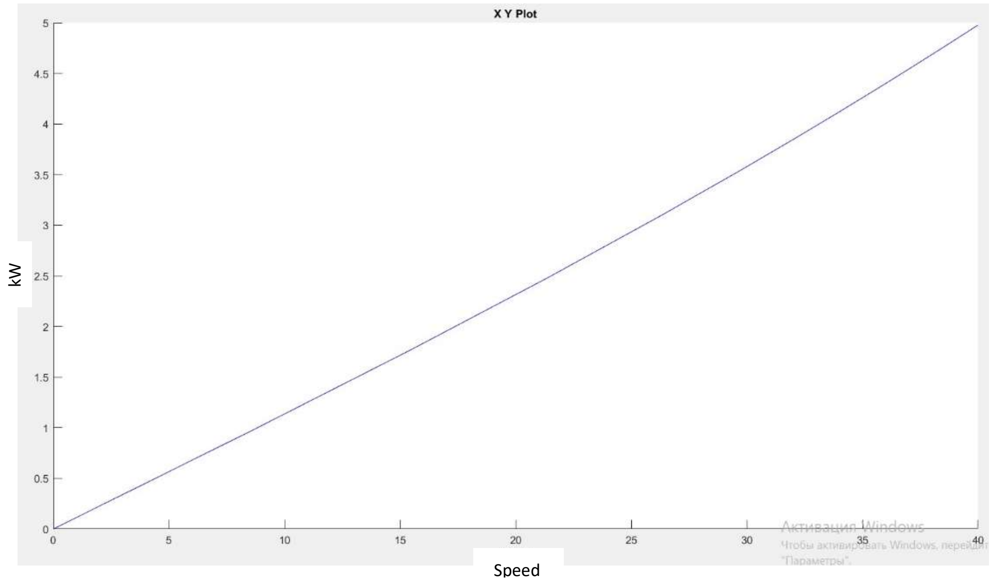


*Figure 16. Correlation of speed and engine power consumption for Tesla Model 3 at 40km/h (4.977 kW)*

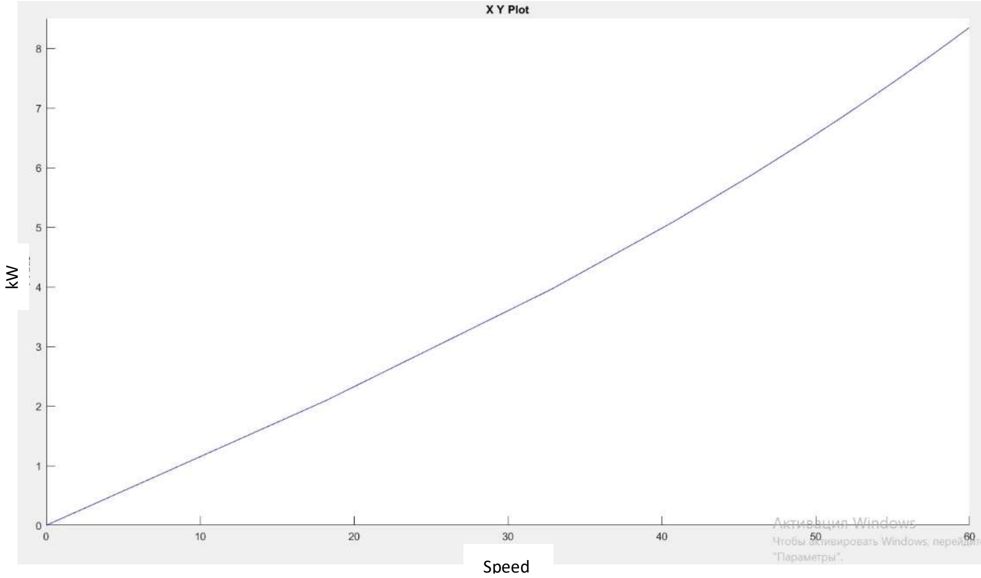


*Figure 17. Correlation of speed and engine power consumption for Tesla Model 3 at 60km/h (8.349 kW)*

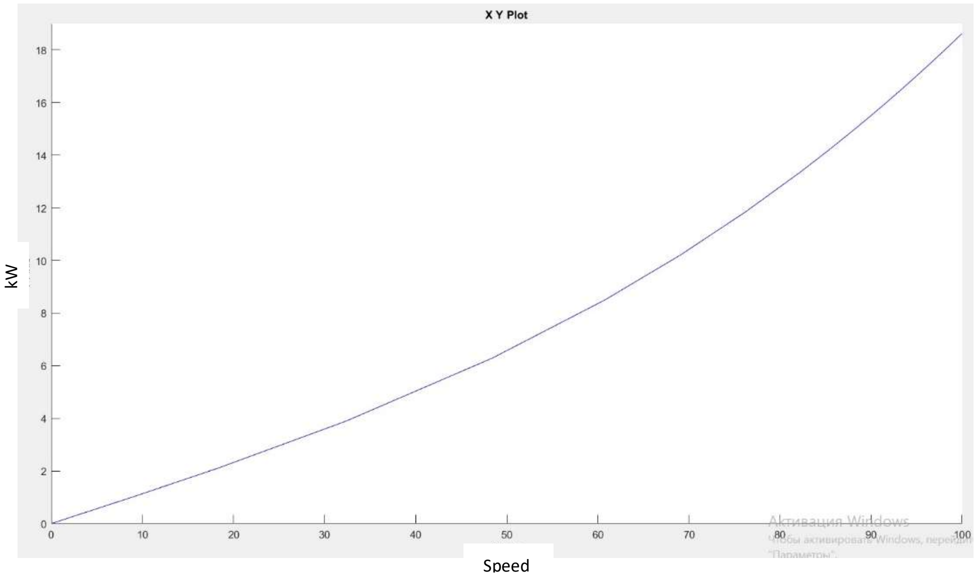


*Figure 18. Correlation of speed and engine power consumption for Tesla Model 3 at 100km/h (18.63 kW)*

The graphs above show that with an increase of speed, the power grows disproportionately, and user need to choose a battery based on what maximum speed he will drive, if driver’s speed does not exceed 60 km/h, then an 10 kW/h extra battery (taking into account its efficiency) is enough for the user.

# 7 CONSTRUCTION AND IMPLEMENTATION OF DEVICE

As described above in Introduction part, this solution is intermediate between regular ICE cars and fully EV. So where can a consumer get this service?

The most prudent plan is to take advantage of the existing regular gas stations, which will require little additional equipment, to store and maintain these batteries. Also at the same gas station, the consumer will be able to conclude a lease contract for this device, in which all terms and conditions are indicated. And after the successful signing of the contract, the user will be able to install this extender in his or her car.

## 7.2 Challenges in making a compact range extender

For the succsess on the market several barriers must be overcome. Firstly, it should be easy to install so that user could install it on the car by himself. Then, for tough climatic conditions termoregulated cases should be avalable. Because baterries very sencetive to harsh conditions, cold and hot weather will decrease performance of the battery (CED Greentech, 2011).

### 7.2.1 Weight of a range extender

So how can an ordinary average driver or a gas station employee be able to independently raise a system of 2-3 modules, when each of which weighs 25.5 kilograms? This is not possible for an almost absolute number of users. Therefore, as described above in Type of The Battery, the main feature of this gadget is mobility and easy to assemble/disassemble.

A user or a gas station employee can put this device into his car without much effort if it is easy to assemble and disassemble into several parts. The following Figures 19, 20 and 21 are an examples of how this system might look:

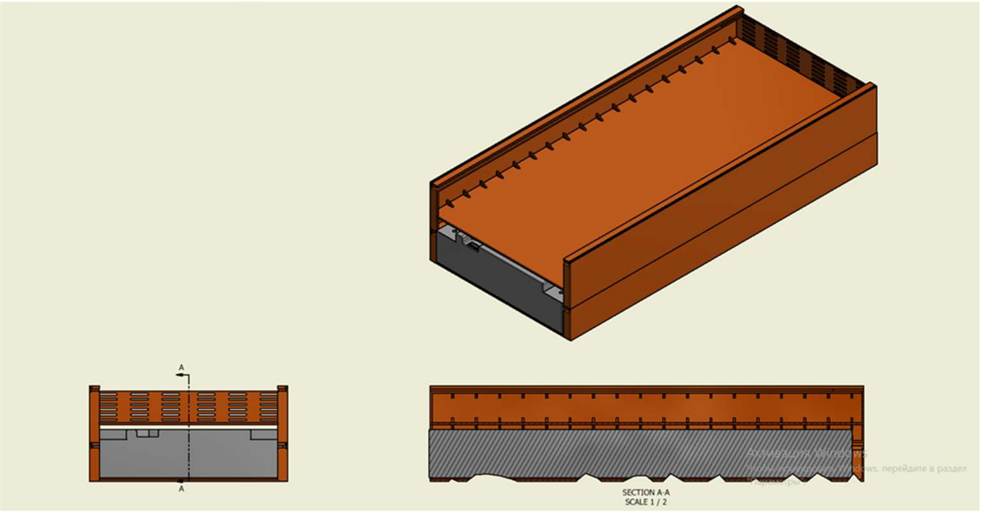


*Figure 19. Battery Module in the case*

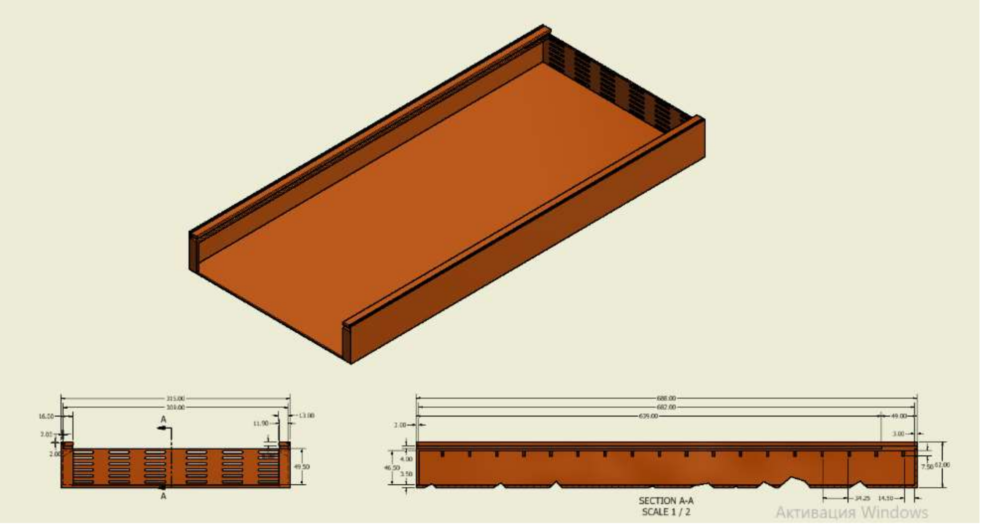


*Figure 20. Bottom case*

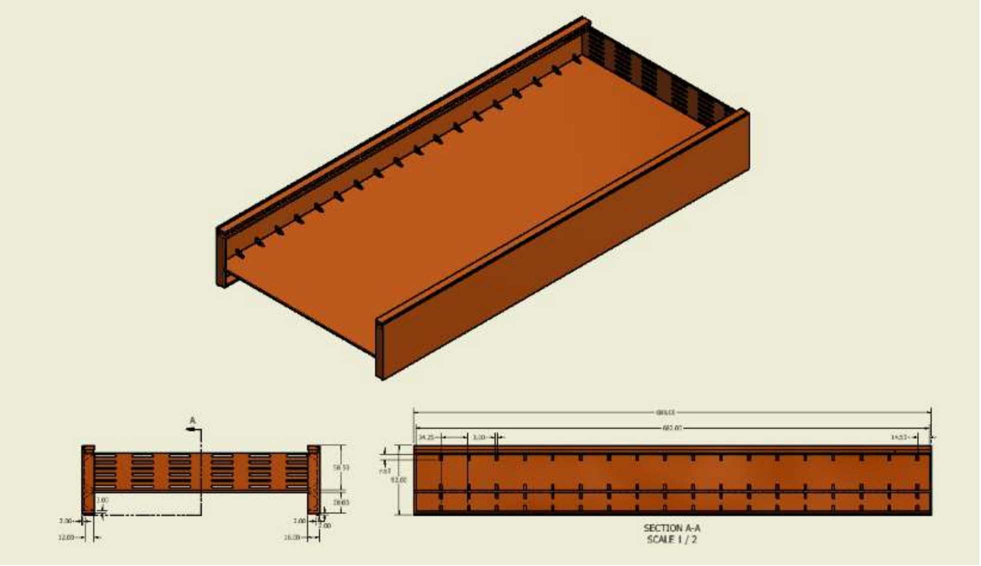


*Figure 21. Second/Third case*

### 7.2.2 Harsh climate conditions

Many potential buyers are confused by how the lithium-ion batteries installed in cars behave in the cold. Since the optimum operating temperature of such a battery, which does not affect the energy resource, is from plus 10 to plus 20 degrees (Autoevolution, 2019).

Most batteries in cold weather lose their capacity. At low temperatures, ion mobility changes, the rate of chemical reactions slows down, and overall battery performance decreases. Low temperature values do not worsen battery parameters, but only temporarily reduce current efficiency and increase the self-discharge rate. But prolonged exposure to cold is undesirable for batteries, since accelerated self-discharge can lead to a complete discharge of the battery. (NRMA, n.d.).

As well as high temperatures, high humidity in combination with the scorching sun are no less dangerous for the condition of a car battery. Summer battery problems are just as common as in the harsh winter months. Undoubtedly, problems differ in their causes and symptoms, however, they can also lead to premature battery failure.

For more severe climatic conditions, such as cold, heat or sudden changes in temperature, temperature-controlled containers can be provided that will allow these modules to be in suitable for work conditions.

### 7.2.3 Current overload

According to the specifications of this battery module, which are given above, the discharge current is 223Ah (1C, continuous), and the peak discharge current is 1000Ah (about 4.3C, 10 seconds). (HSR Motors, n.d.).

To get a battery system of sufficient capacity that does not take up much space in the trunk, we have to connect these modules in parallel. But according to Ohm's law, a system of two or three such modules, we will have 446 and 669Ah, respectively. And after looking at the characteristics of the cables that are suitable for such current rates, there is need a cross-section diameter of about 30 cm. Therefore, to solve the difficulties described above, I propose a solution, which is described further:

For example, we have 2-3 modules (each 24VDC, 223A), they are in the trunk, powered to one of the motors. To control the on/off of the batteries due to contactors, we have to use the charge sensors on the batteries. And only then connect the contactors to them. And the contactors would switch them with a certain frequency to give uninterrupted power to the inverter. And at the same time maintaining the balance between the batteries (if they were initially balanced). We would not have overload in the network from a large amperage, as with a parallel connection. And the required battery capacity would be preserved, which we would not be able to get with serial connection.

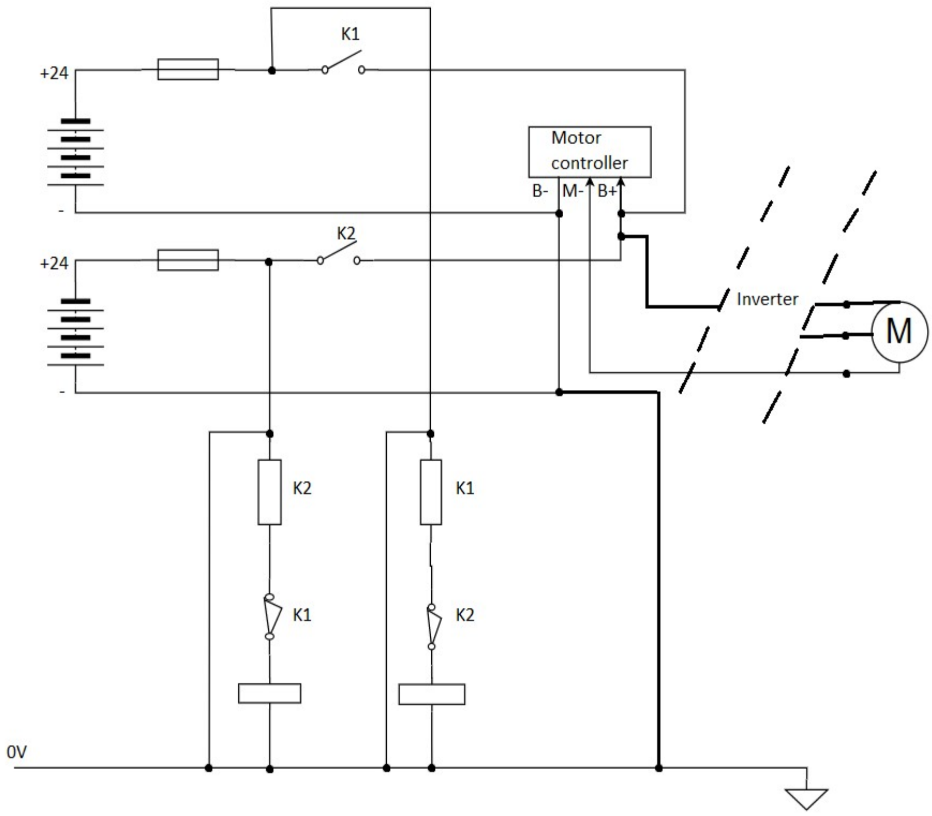


*Figure 22. Power Bank circuit*

# 8 RECOMMENDATIONS

There are several possible ways to implement this solution. This can be done by an EV manufacturer that already has its own battery production line or existing manufacturers specializing in battery production. EV manufacturers have the advantage of being the only ones who can programmatically authorize these operations with the car. Moreover, they can design in advance a place for installing additional batteries.

But since there are many manufacturers of electric vehicles in the world, the question arises of unifying the Power banks. Therefore, for a company with a large model selection of EVs and several battery factories, such as Tesla, this reasonable approach will help attract more new customers and at the same time reduce costs.

However, for major car manufacturers that own multiple brands, but do not produce EVs in large quantities, for example: Volkswagen Auto Group (VAG), Toyota, Renault–Nissan–Mitsibishi, General Motors (GM), FCA (Fiat Chrysler Automobiles) and Groupe PSA – buying universal Power banks from the manufacturers specializing in battery production is the best way to globalize electrical vehicle market.

# 9 CONCLUSIONS

Electric cars are gradually entering our everyday life. A decade ago , electric vehicles were a curiosity for most people, but now everyone understands that they are the future. Unfortunately, a major obstacle to the public consumption of electric vehicles still is their charging time. Currently, most countries do not think enough about the infrastructure of public charging stations, where EV owners could quickly charge their vehicles. Fortunately, big manufacturers like Tesla are constantly looking for ways to improve the quality and capacity of their batteries. Perhaps the most exciting news in the last couple of years are the Supercharging stations. However, even supercharging does not compare with how quickly a regular ICE car can refuel.

It seems that Power Banks can be the key to solving problems for people who doubt the purchase of an electric vehicle due to the inconvenience of charging them. But for now, reality is far from it. First of all, the prices for the production of batteries should fall significantly, so that manufacturers would have an economic interest in establishing the production of additional batteries. Humanity must also switch to renewable energy sources, since so far most of the electricity is extracted from the bowels of the Earth - produced by coal-fired power plants and etc., which increasing can cause greater environmental pollution compared to gas-powered cars. (World Economic Forum, 2017).

In conclusion, the EV market is very competitive, and the car makers that produce them are always trying to increase the range, create more beautiful and ergonomic designs, make the car faster and also add more functions to make the driver’s life easier. On the other hand, according to the results given here, it is just a matter of time when EV Power Banks will be integrated into our daily lives. Just like car- bike- or scooter sharing services.

In my opinion, the first company to offer its customers a complete replacement for ICE cars will defeat the others in business. So we can say that in the near future it will be economically and technologically feasible to produce and implement Electric Vehicle Power Banks.

# REFERENCES

ACEA European Automobile Manufacturers Association (2019). *Vehicles in Use on the EU's roads.* Retrieved 12th August 2019 from https://www.acea.be/statistics/tag/category/vehicles-in-use

Avto Informator (2018). *Automobile concerns: who owns the popular car brands?* Retrieved 14th May 2020 from https://avto.informator.ua/2018/08/28/avtomobilnye-kontserny-komu-prinadlezhat-populyarnye-marki-mashin/

Bhatt, D (2017). What is the difference between VFD and VVVFD? Retrieved 12th August 2019 from https://www.quora.com/What-is-the-difference-between-VFD-and-VVVFD

BioScience (2017). World Scientists' Warning to Humanity: A Second Notice. Volume 67, Issue 12, P. 1026–1028. Retrieved 12th August 2019 from https://academic.oup.com/bioscience/article/67/12/1026/4605229

CED Greentech (2011). Battery Life and Performance Factors. Retrieved 12th August 2019 from https://www.cedgreentech.com/article/battery-life-and-performance-factors

CHE (2017). Main sources of carbon dioxide emissions. Retrieved 12th August 2019 from https://www.che-project.eu/news/main-sources-carbon-dioxide-emissions

CleanTechnica (2016). Tesla's 3-Phase 4-Pole AC Induction Motor — Why Nikola Tesla's 19th Century Induction Motor Is The Ideal Choice For The 21st Century Electric Car. Retrieved 12th August 2019 from https://cleantechnica.com/2016/05/30/nikola-teslas-19th-century-induction-motor-ideal-choice-21st-century-electric-car/

CleanTechnica (2018). Tesla Model 3 Motor — Everything I've Been Able To Learn About It. Retrieved 12th August 2019 from https://cleantechnica.com/2018/03/11/tesla-model-3-motor-in-depth/

Electrek (2018). *Nissan Leaf Battery State of Health vs Years Of Use.* Retrieved 12th August 2019 from https://electrek.co/2018/04/14/tesla-battery-degradation-data/

Electrek (2018). *Tesla Model S/X Mileage vs Remaining Battery Capacity.* Retrieved 12th August 2019 from https://electrek.co/2018/04/14/tesla-battery-degradation-data/

Electrotransport (2017). Calculation of electric motor power and battery capacity. Retrieved 12th August 2019 from https://electrotransport.ru/ussr/index.php?topic=43434.0

Enel X (2019). How Long Does It Take to Charge a Tesla? Retrieved 14th May 2020 from https://evcharging.enelx.com/news/blog/577-how-long-does-it-take-to-charge-a-tesla

EVANNEX (2018). A tour of the Gigafactory reveals how tesla's batteries are constantly improving. Retrieved 12th August 2019 from https://evannex.com/blogs/news/a-tour-of-the-gigafactory-reveals-how-tesla-s-batteries-are-constantly-improving

Ganthia, B (2015). Variabe voltage and variable frequency drives. P. 3. Retrieved 12th August 2019 from https://www.slideshare.net/bibhuprasadganthia/variabe-voltage-and-variable-frequency-drives

Golden Motor (n.d.). Do-it-yourself electric car. Retrieved 12th August 2019 from https://goldenmotor.ru/electromobil-svoimi-rukami/

Guillen, J (2018). President of Automotive Operations, Tesla. Interview 29 November 2018.

Hartman, C (2014). What is a variable frequency drive? Retrieved 12th August 2019 from https://www.vfds.com/blog/what-is-a-vfd

Hedges & Company (2019). *U.S. Vehicle registration statistics from registration databases.* Retrieved 12th August 2019 from https://hedgescompany.com/automotive-market-research-statistics/auto-mailing-lists-and-marketing/

HSR Motors. *85-Type battery module*. Retrieved 12th August 2019 from https://hsrmotors.com/products/battery_modules

IEA (2018). Global EV Outlook 2018. Retrieved 12th August 2019 from https://www.iea.org/reports/global-ev-outlook-2018

IEA (2019). Battery storage is (almost) ready to play the flexibility game. Retrieved 12th August 2019 from https://www.iea.org/commentaries/battery-storage-is-almost-ready-to-play-the-flexibility-game

InsideEVs (2018). 3 Ways To Ruin Your Tesla Battery, Plus What It Costs To Replace It. Retrieved 12th August 2019 from https://insideevs.com/news/339193/3-ways-to-ruin-your-tesla-battery-plus-what-it-costs-to-replace-it/

JATO Dynamics (2019). *Tesla Model 3 becomes Europe's best-selling pure electric vehicle in February in its first full month on the market.* Retrieved 12th August 2019 from https://www.jato.com/tesla-model-3-becomes-europes-best-selling-pure-electric-vehicle-in-europe/
Keeling, R (2018). Professor of Geochemistry, Scripps Institution of Oceanography. Interview 19 September 2018.

NACS (2019). *U.S. Convenience Store Count.* Retrieved 12th August 2019 from
https://www.convenience.org/Research/FactSheets/ScopeofIndustry/IndustryStoreCount

National Park Service (2019). What is Climate Change? Retrieved 12th August 2019 from https://www.nps.gov/goga/learn/nature/climate-change-causes.htm

NRMA (n.d.). How does cold weather affect your car battery? Retrieved 12th August 2019 from https://www.mynrma.com.au/cars-and-driving/roadside-assistance/car-batteries/resources/how-does-cold-weather-effect-your-car-battery

O'Kane, S (2019). Tesla's Model 3 was the best-selling EV in the world last year. *The Verge*. Retrieved 12th August 2019 from https://www.theverge.com/2019/2/22/18236707/tesla-model-3-2018-best-selling-ev-global

Quora (2017). *How many li-ion batteries are there in a Tesla Model S? Tesla Model S Battery Pack.* Retrieved 12th August 2019 from https://www.quora.com/How-many-li-ion-batteries-quantity-are-there-in-a-Tesla-Model-S

SAGE Journals (2017). *The Anthropocene equation. Owen Gaffney, Will Steffen. First Published February 10, 2017.* Retrieved 12th August 2019 from https://journals.sagepub.com/doi/abs/10.1177/2053019616688022?journalCode=anra

ScienceAlert (2019). It's Official: Atmospheric CO2 Just Exceeded 415 ppm For The First Time in Human History. Retrieved 12th August 2019 from https://www.sciencealert.com/it-s-official-atmospheric-co2-just-exceeded-415-ppm-for-first-time-in-human-history

Scripps Institution of Oceanography. *The Keeling Curve*. Retrieved 12th August 2019 from https://scripps.ucsd.edu/programs/keelingcurve/
Tesla (2019). Charge on the Road. Retrieved 12th August 2019 from https://www.tesla.com/supercharger

Tesla Forums (2013). *Current Model S motor limitations*. Retrieved 14th May 2020 from https://forums.tesla.com/nl_BE/forum/forums/current-model-s-motor-limitations

Tesla Motors Club (2015). *Motor Inductance, Resistance and Maximum RPM: Estimated vs Actual.* Retrieved 14th May 2020 from https://teslamotorsclub.com/tmc/threads/tech-motor-inductance-resistance-and-maximum-rpm-estimated-vs-actual.46353/

The King Eduka (2019). Master Kisi-Kisi SBMPTN Saintek. P. 455. Retrieved 12th August 2019 from https://books.google.fi/books?id=bWlvDwAAQBAJ&pg=PA455&lpg=PA455

Union of Concerned Scientists (1992). 1992 World Scientists' Warning to Humanity. Retrieved 12th August 2019 from https://www.ucsusa.org/resources/1992-world-scientists-warning-humanity

Warm Heart Worldwide (n.d.). What is Climate Change? Retrieved 12th August 2019 from https://warmheartworldwide.org/climate-change/?gclid=EAIaIQobChMI9rGwrpfp6QIVBcAYCh07-wrLEAAYASAAEgLT3fD_BwE

Wertheimer, E. (2018). *Model a Car and Design a PID Controller in MATLAB/SIMULINK.* Udemy. Retrieved 14th May 2020 from https://www.udemy.com/course/tesla-model-s-control-simulink/

Will Elder. (2019). *What is Climate Change?* Retrieved 12th August 2019 from https://www.nps.gov/goga/learn/nature/climate-change-causes.htm

Worldometer (2019). Europe Population. Retrieved 12th August 2019 from https://www.worldometers.info/world-population/europe-population/

Worldometer (2019). United States Population. Retrieved 12th August 2019 from https://www.worldometers.info/world-population/us-population/